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XVI.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XXXVI. — ON THE INFLUENCE OF THE STRENGTH OF THE MAGNET IN A MAGNETO TELEPHONE RECEIVER.

By Charles R. Cross and Harry E. Hayes.

Presented November 12, 1890.

The present investigation is a continuation of the research described in a paper by Messrs. Cross and Williams, previously published in these Proceedings (vol. xxiv. p. 113). With a magneto telephone transmitter it was found that, as the strength of the magnet was increased, the induced current produced by a definite motion of the diaphragm increased quite rapidly to a maximum, and then gradually decreased. With diaphragms of different thickness it was found that, as the field necessary to saturate the diaphragm increased in strength, the maximum value of the induced current occurred with a greater strength of field, and also that the value of this maximum current increased with the thickness of the diaphragm, other things remaining the same. One series of measurements, however, whose results are shown in curve No. 23, Figure 2, of that article, seemed to be at variance with this conclusion, a discrepancy which was explained on the supposition that the supports holding the cam-rod by which the diaphragm was thrust forward yielded to a material extent with the thicker and stiffer diaphragm, which, by lessening the motion of this, would produce the observed result of a diminished current.

A series of measurements was first made in order to ascertain whether the above conclusion was correct. The apparatus employed was identical with that described in the previous article referred to, but the supports carrying the cam-rod were much increased in rigidity. The same diaphragms were employed as in the earlier experiments. The results were such as to show that the explanation of the discrepancy suggested was the true one, as will be seen on an examination of Tables I., II., and III. The diaphragms used were of iron, and of the same thickness as in the previous experiments, viz. Nos. 21, 22, and 23, B. W. G., corresponding to a thickness of 0.032 in., 0.027 in., and 0.024 in., respectively.

TABLE I.

Diaphragm, Sheet Iron, No. 21.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	0.0	.384	105.7
.070	19.0	.441	102.0
.119	38.0	.492	101.3
.158	49.5	.584	101.0
.202	64.0	.637	98.0
.246	77.7	.740	92.3
.292	93.3	.900	88.5
.344	99.0		

TABLE II.

Diaphragm, Sheet Iron, No. 22.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	0.0	.380	97.5
.070	19.5	.425	96.8
.105	35.5	.456	96.7
.141	39.7	.514	94.0
.176	47.0	.577	88.0
.222	63.3	.700	84.3
.258	73.7	.781	76.5
.306	86.0	.916	71.5
.344	94.0		

TABLE III.

Diaphragm, Sheet Iron, No. 23.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	0.0	.325	86.3
.070	15.5	.364	90.0
.123	30.5	.492	82.5
.155	42.3	.558	76.0
.194	53.8	.637	66.5
.236	65.0	.700	61.5
.268	75.7	.900	50.8

It was feared, however, that further difficulty might be met with from yielding of the supports of the cam-rod when heavy diaphragms were used, so that a modification of the apparatus was thought to be desirable. The cam-rod was therefore provided with a brass diaphragm-holder, so that the diaphragm, being carried by this, was moved bodily forward by the longitudinal motion of the cam-rod. A series of observations made with the same diaphragms used in the experiment last described gave the results shown in Tables IV., V., and VI., which are in substantial accord with those reached with the earlier form of the apparatus as given in Tables I., II., and III. From these tables the curves shown in Figure 1 were constructed. The induced currents are represented by abscissas, the strengths of the field by ordinates.

TABLE IV.

DIAPHRAGM, SHEET IRON, NO. 21.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	1.7	.620	124.3
.123	28.3	.649	118.3
.194	44.0	.700	111.0
.262	55.8	.787	102.9
.306	63.9	.862	96.5
.384	82.3	.976	88.5
.466	98.5	1.213	68.5
.554	118.5		

TABLE V.

DIAPHRAGM, SHEET IRON, NO. 22.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	0.5	.514	86.7
.125	22.5	.596	91.4
.191	36.3	.654	89.0
.268	45.3	.716	81.5
.302	52.8	.807	77.0
.325	56.9	.983	69.3
.420	72.3	1.065	56.3
.466	84.3	1.235	52.3

TABLE VI.

DIAPHRAGM, SHEET IRON, NO. 23.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	0.0	.488	90.5
.126	20.8	.577	87.5
.134	34.9	.654	80.3
.266	43.8	.716	72.0
.302	52.4	.784	57.4
.337	62.5	.888	43.2
.412	83.0	1.036	30.5
.449	89.3	1.235	24.5

The numbers 21, 22, 23, affixed to the curves of Figure 1, indicate the thickness of the corresponding diaphragms by their gage number (B.

W. G.). The curves show that with the diaphragms Nos. 21, 22, 23, the maximum induced currents were 124, 93, 91, respectively, corresponding to relative strengths of field 61, 56, 49. The results reached in the earlier article are fully confirmed by these figures, which prove that, within the limits of the experiments, the maximum current is greater, and is reached with a stronger field, as the diaphragm is thicker.

An examination of the curves of Figure 1 shows that the point of maximum current is less distinctly marked with the thinner diaphragms than with the thickest. We are inclined to believe this to be an accidental peculiarity, due to a slight yielding of the diaphragm, which was fastened at its edges and which when thin would tend to bulge towards the magnet, thus causing its whole motion to be performed in a stronger field, and so giving rise to a stronger induced current than would otherwise be the case. An extremely slight displacement of this kind will produce a noticeable difference in the resulting induced current. This effect may also have acted to diminish somewhat the difference between the maximum current obtained with

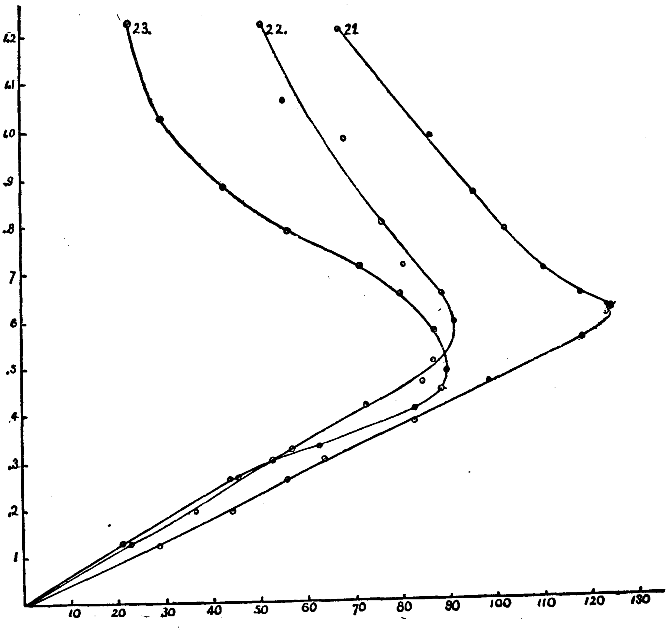

FIG. 1.

the two thinnest diaphragms, which difference is much less than the difference between the maximum current with the two thickest ones.

Care was taken in all the experiments described in this paper that the magnet of the apparatus should be far below saturation, even with the strongest magnetizing currents which were used.

Our experiments were next directed to a study of the conditions operative in the magneto receiver, and particularly to ascertain the effect of a varying degree of magnetization in the magnet of the receiver upon the change in its strength when subjected to the action of a slight current of the same order of magnitude as that used in telephony.

The apparatus employed consisted of a core of soft Norway iron, six inches long and a quarter of an inch in diameter, and provided with a suitable magnetizing coil. A diaphragm was placed opposite one end of the core, as in the usual magneto receiver. This end of the core also carried two coils of fine wire, like the ordinary telephone magnet coil, one having a resistance of about 130 ohms, the other of about 190 ohms. The former of these coils was connected with a storage cell, a fixed resistance, and a key. By means of this apparatus a current of suitable magnitude could be caused to traverse the coil, which evidently corresponds to the coil of the ordinary receiver, and which we have called the "line coil." The effect of this current will be slightly to increase or decrease the magnetization of the bar magnet, as in the receiver itself. The second fine wire coil is a "measuring coil," and is connected in circuit with a ballistic galvanometer, from whose deflection when a current was sent through the first fine-wire coil the effect of this current on the magnet of the receiver could be determined. A magnetometer arranged in the usual manner showed the relative strength of the field of the receiver magnet under differing conditions of magnetization.

The observations consisted in adjusting the magnitude of the current through the magnetizing coil so as to give a certain deflection of the magnetometer needle. The magnetizing circuit included a suitable resistance coil, by the use of which any desired current could readily be secured. The key was then pressed, so that a certain current flowed through the line coil. The proper value was given to this current by means of a rheostat. The induction occurring in the measuring coil gave rise to a transient current through this circuit, the value of which was known from the deflection of the needle of the ballistic galvanometer included in it. Of course the key had to be kept down until the observation was completed, and it was also necessary, on account of the self-induction of the measuring circuit, always to read either on opening or on closing the key. In our experiments the latter alternative was chosen.

The results were plotted as previously by using the relative strength of the field as expressed by tangents of the magnetometer deflections as ordinates, and the induced currents in terms of an arbitrary unit as abscissas. The deflection of the ballistic galvanometer used was proportional to the strength of the transient current passing through its coils.

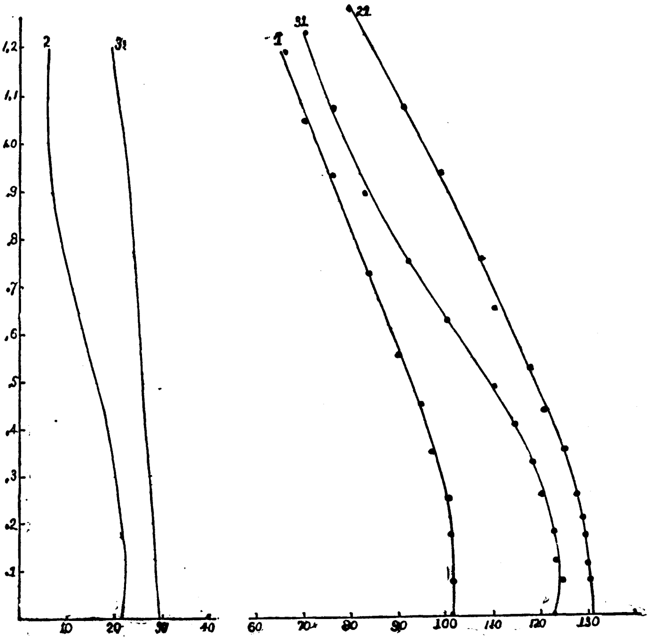

FIG. 2.

A series of observations was first made with the diaphragm removed, in order to study the deportment of the core alone under varying degrees of magnetization. The results are given in Table VII., and are shown graphically in Curve 1, Figure 2. It appears from these, that with increasing magnetization of the core the induced current remains nearly constant for a time, and then diminishes rapidly and at an increasing rate, which afterwards becomes nearly constant, a result which would be anticipated from the corresponding diminution in the magnetic change which a small current in the line coil would produce.

The current which traversed the line coil was six milliamperes, a value which was used in most of the measurements, it having been found by trial that the general character of the results was the same as when a smaller line current was used, while the greater magnitude of the deflection of the current induced in the secondary measuring circuit allowed more satisfactory readings to be made than if the line current were smaller.

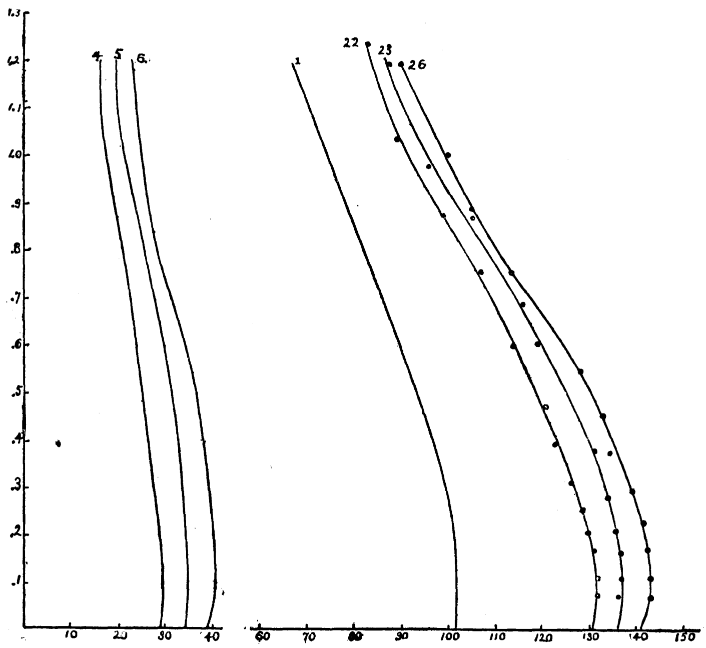

FIG. 3.

A corresponding series of measurements with a diaphragm of ferrotype iron, No. 31, B. W. G., 0.010 in. in thickness, gave the results found in Table VIII. and shown in Curve 31, Figure 2. Curve 2, Figure 2, is constructed with abscissas equal to the difference of the corresponding abscissas of Curves 31 and 1, and shows for various strengths of field the increase of the induced current due to the presence of the diaphragm, an interesting illustration of the action to which Du Moncel ascribed the chief efficacy of the diaphragm.

In order to study the effect of the thickness of the diaphragm, further measurements were made, using sheet iron diaphragms Nos. 21, 22, 23, 26, B. W. G., whose thickness was 0.032 in., 0.027 in., 0.024 in., and 0.018 in., respectively. The results of these measurements will be found in Tables IX. to XII. inclusive, and from them the Curves 21, Figure 2, and 22, 23, 26, Figure 3, were constructed. The numbers attached to the curves indicate the gage of the diaphragm. The curves numbered 3, 4, 5, 6, respectively, are constructed to show the effect due to the addition of the diaphragm of thickness indicated by the gage number, as already explained in the case of Curve 2, Figure 2.

TABLE VII.

No Diaphragm.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	101.5	.554	90.7
.070	101.8	.727	84.3
.167	101.2	.933	77.6
.244	101.0	1.043	71.8
.348	97.8	1.192	67.7
.445	95.2		

TABLE VIII.

Diaphragm, Ferrotype Iron, No. 31.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	123.0	.488	110.9
.072	124.4	.625	101.7
.112	123.4	.754	93.2
.176	123.0	.897	84.0
.259	120.5	1.072	77.9
.327	118.7	1.235	72.0
.402	115.4		

TABLE IX.

Diaphragm, Sheet Iron, No. 21.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	131.0	.437	121.7
.073	130.2	.521	118.4
.107	130.0	.649	111.3
.167	129.7	.754	108.5
.207	129.2	.933	100.2
.257	128.0	1.076	92.2
.356	125.4	1.280	81.4

TABLE X.

DIAPHRAGM, SHEET IRON, No. 22.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	130.8	.394	122.2
.073	131.4	.475	120.2
.112	131.6	.601	113.9
.169	130.2	.754	106.4
.204	129.2	.875	98.4
.255	128.2	1.039	88.7
.313	126.0	1.235	82.7

TABLE XI.

DIAPHRAGM, SHEET IRON, No. 23.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	136.0	.488	128.4
.068	136.0	.603	118.4
.107	136.7	.690	115.5
.167	136.4	.869	104.9
.211	135.7	.979	95.4
.281	133.9	1.196	87.2
.380	130.9		

TABLE XII.

DIAPHRAGM, SHEET IRON, No. 26.

Strength of Field.	Induced Current.	Strength of Field.	Induced Current.
.000	140.9	.454	132.2
.068	142.7	.543	128.0
.112	142.4	.625	124.7
.175	142.0	.754	113.0
.229	141.4	.885	104.4
.298	138.7	1.004	99.2
.376	134.0	1.196	89.2

Several series of measurements were made with currents of widely different strengths, and with the thinnest and the thickest of the diaphragms used in these experiments, in order to ascertain whether the induced current in the measuring coil was proportional to the inducing line current, and since this was found to be sensibly the case, the strength of six milliamperes was adopted, as already stated.

Considerable trouble was experienced in obtaining satisfactory consecutive readings of the deflections, on account of the close proximity of the laboratory to the streets, rendered especially disturbing by the presence of the electric railway. The difficulty was avoided as far as possible by working at night. In order to indicate the character of our results so far as the deflections of the ballistic galvanometer are concerned, the following values (Table XIII.) are given, from which the deflections in Table XII. are derived.

TABLE XIII.

Deflections.			Mean.	Half-deflections.
A	B	C		
281	283	281	281.7	140.9
285	286	285	285.3	142.7
285	284	285	284.7	142.4
284	284	284	284.0	142.0
283	283	282	282.7	141.4
277	278	277	277.3	138.7
269	268	267	268.0	134.0
263	265	265	264.3	132.2
256	257	255	256.0	128.0
249	250	249	249.3	124.7
226	225	227	226.0	113.0
210	208	208	208.7	104.4
199	199	197	198.3	99.2
178	178	179	178.3	89.2

It will be seen from inspection of any one of the various curves last referred to, that as the strength of the field increases, the induced current increases, and then gradually diminishes. This would of course be anticipated, as the increased magnetization of both the core and the diaphragm increases the strength of field in which the latter moves, and at the same time diminishes the susceptibility of both masses of metal to magnetization. The effect of the former predominates slightly at first, but is overpowered by the latter cause when the magnetization is increased. The Curves 2, 3, 4, 5, 6, show that the addition of the diaphragm causes a greater increase of the induced current at low than at high magnetizations of the core, as would naturally be anticipated.

Curves 21 and 22 are so nearly alike that they have been placed in separate figures to avoid confusion. It would seem from this coincidence that above No. 22 an increased thickness of diaphragm causes little effect.

A comparison of the curves will show that, with the exception of Curve 31, for which the diaphragm was of ferrotype iron, the value of the maximum induced current is greater according as the diaphragm is thinner; and also that the strength of field corresponding to this maximum current is likewise greater the thinner the diaphragm.

The following approximate values were found from constructions of the curves on a large scale.

For	No.	26,	Maximum	Current =	142,	Field =	.18
"	"	23,	"	"	137	"	.13
"	"	22,	"	"	132	"	.10
"	"	21,	"	"	131	"	.06

It also appears that with the thinner diaphragms the decrease of the induced current with increase of field, after the maximum value of the current is reached, is more rapid than with the thicker ones. Moreover, the deviation of the latter portion of the curve from a straight line is greater in the case of the thinner diaphragms.

The greater value of the maximum induced current with the thin than with the thick diaphragm would naturally be ascribed to the less stiffness of the former, and its consequent greater motion when a current passes through the line, although its smaller mass and greater ease of saturation must in a measure counterbalance this effect. The quicker approach of the thin diaphragm towards saturation will explain the more rapid falling off of the current with it, and also the less uniform rate of this change as the field increases. Curves 3, 4, 5, 6, showing the effect of the diaphragm, still further illustrate these facts.

It should be observed that the results which we have described do not necessarily show the varying acoustic effect of the receiver, since the amplitude of the motion of the diaphragm rather than the simple amount of the change of strength of the magnet determines the magnitude of the resulting air-waves, — at least according to the view commonly held. We hope to return to the study of this part of the problem, which is rendered somewhat difficult on account of the very small motion of the diaphragm.

Rogers Laboratory of Physics,
October, 1890.